Summary

These experiments measure neuronal responses from anterior lateral motor cortex (ALM) and deep cerebellar nucleus (CN) of adult mice performing pole location discrimination with a short-term memory. In some cases, we manipulate activity of one brain region while recording from the other region.

Dataset:

Li N (2018). Extracellular recordings from anterior lateral motor cortex (ALM) and cerebellar nucleus neurons of adult mice performing a tactile decision behavior.

Data included in this release:

34 sessions (9 mice), ALM recording during fastigial or dentate photoactivation
20 sessions (4 mice), ALM recording during DCN photoinhibition
(Data already available at: http://dx.doi.org/10.6080/K0NS0S26)

185 sessions (18 mice), CN recording. In some sessions, ALM photoinhibition was tested
(Data included in this data release).

Data from the follow publication:

Gao Z, Davis C, Thomas AM, Economo MN, Abrego AM, Svoboda K, De Zeeuw CI, Li N (2018). A cortico-cerebellar loop for motor planning. Nature, Nov;563(7729):113-116. doi: 10.1038/s41586-018-0633-x. Epub 2018 Oct 17.

Animals

This dataset contains data from 70 mice (age > P60, both male and female mice, Supplemental Table 1). 9 C57B1/6 mice were used for ALM recordings during photo-activation of the CN. 4 L7-cre (Lewis et al., 2004) crossed to Ai32 (Rosa26-LSL-ChR2-EYFP, JAX Stock#012569) (Madisen et al., 2012) mice were used for ALM recordings during CN photo-inhibition.
10 C57B1/6 mice were used for CN recording experiments. 8 VGAT-ChR2-EYFP mice (Jackson laboratory, JAX Stock#014548) (Zhao et al., 2011) were used for CN recordings during ALM photo-inhibition.

Experimental methods

Detailed experimental methods are described in the manuscript (Gao et al 2018).

Behavior

Mice measured the location of an object using their whiskers during a sample epoch (1.3 s) (O'Connor et al., 2010). After the sample epoch they must hold their decision about object location in memory for a delay period (1.3 s) (Guo et al., 2014). At the end of the delay period, an auditory cue (0.1) instructed the mice to report their decision with directional licking ("lick left"/"lick right").

CN ChR2 photo-activation

For ChR2 photo-activation of the CN, wild-type mice injected with AAV2-hSyn1-(h134R)ChR2-EYFP virus were used. Light from a 473 nm laser (Laser Quantum, Part# Gem 473) was controlled by an acousto-optical modulator (AOM; Quanta Tech) and a shutter (Vincent Associates). To prevent the mice from distinguishing photostimulation trials from control trials using visual cues, a 'masking flash' was delivered using 470 nm LEDs (Luxeon Star) near the eyes of the mice. The masking flash began as the pole started to move and continued through the end of the epoch in which photostimulation could occur. The photostimulus was pulses of light (5 ms pulse duration) delivered at 20 Hz and a range of peak powers (5, 10, 15mW). The power values reported in the paper indicate average powers (0.5, 1, 1.5 mW). The powers were measured at the fiber tip. The photostimulus started at the beginning of a task epoch and continued for 0.455 s (10 pulses).

CN photo-inhibition

In L7-cre × Ai32 mice, ChR2 was expressed in cerebellar Purkinje cells. We photostimulated Purkinje cells to inhibit neurons in the CN. The photostimulus was a 40 Hz sinusoid (average power, 4.5 mW) lasting for 1.3 sec, including a 100-200ms linear ramp during the laser offset to reduce rebound neuronal activity.

ALM photo-inhibition

ALM is centered on bregma anterior 2.5 mm, lateral 1.5 mm (Chen et al., 2017; Guo et al., 2014; Li et al., 2016). For photo-inhibition of ALM, we photostimulated cortical GABAergic neurons in VGAT-ChR2-EYFP mice (8 mice). Photostimulation was performed through the clear-skull cap implant by directing the blue laser over the skull (beam diameter: 400 μm at 4σ, bregma anterior 2.5 mm, lateral 1.5 mm). The light transmission through the intact skull was 50% (Guo et al., 2014). We photo-inhibited ALM for 1.3 s at the beginning of the delay epoch, including a 100 ms linear ramp at the laser offset to minimize rebound excitation. This photostimulus was empirically determined to produce robust photo-inhibition in ALM (Guo et al., 2014; Li et al., 2016). The photo-inhibition silenced 90% of spikes in a cortical area of 1mm radius (at half-max) through all cortical layers. For unilateral ALM photo-inhibition, we used a 40 Hz sinusoidal photostimulus (1.5mW average power at the skull surface) at 2.5 mm anterior and 1.5 mm lateral from bregma. For bilateral ALM photo-inhibition, we used a constant photostimulus and a scanning galvo (GVSM002, Thorlabs), which stepped the laser beam sequentially through the photo-inhibition sites at the rate of 1 step per 5 ms (step time: 0.2 ms; dwell time: 4.8 ms; measured using a photodiode). 8 photo-inhibition sites were spaced in 1 mm at anterior 2-3 mm and lateral 1-2 mm from bregma, covering ALM. Peak power was adjusted based on the number of photo-inhibition sites to achieve 1.5 mW average power per site.

Electrophysiology

Extracellular spikes were recorded using 32-channel NeuroNexus silicon probes (Part# A4x8-5mm-100-200-177) or 64-channel Cambridge NeuroTech silicon probes (H2 acute probe, 25 μm spacing, 2 shanks). The 32-channel voltage signals were multiplexed, digitized by a PCI6133 board at 400 kHz (National Instruments) at 14 bit, demultiplexed (sampling at 25,000 Hz) and stored for offline analysis. The 64-channel voltage signals were amplified and digitized on an Intan RHD2164 64-Channel Amplifier Board (Intan Technology) at 16 bit, recorded on an Intan RHD2000-Series Amplifier Evaluation System (sampling at 20,000 Hz) using Open-Source

RHD2000 Interface Software from Intan Technology (version 1.5.2), and stored for offline analysis.

The extracellular recording traces were band-pass filtered (300-6 kHz). Events that exceeded an amplitude threshold (4 standard deviations of the background) were subjected to manual spike sorting to extract single-units (Guo et al., 2014).

Data analysis

For ALM recordings, units are classified based on spike shape. Spike widths were computed as the trough-to-peak interval in the mean spike waveform. Units with spike width < 0.35 ms were defined as fast-spiking neurons (82/1309) and units with spike widths > 0.45 ms as putative pyramidal neurons (1194/1309). Units with intermediate values (0.35 - 0.45 ms, 33/1309) were excluded from analyses. This classification was previously verified by optogenetic tagging of GABAergic neurons (Guo et al., 2014).

For CN recordings, units are classified based on recording location. We estimated unit locations based on recording track labeling, recording depth, and the lamination of activity patterns across the recording shanks. In *post-hoc* histology, CN boundaries were visible in DAPI staining.

References

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O'Connor, D.H., Clack, N.G., Huber, D., Komiyama, T., Myers, E.W., and Svoboda, K. (2010). Vibrissa-based object localization in head-fixed mice. The Journal of neuroscience : the official journal of the Society for Neuroscience *30*, 1947-1967.

Zhao, S., Ting, J.T., Atallah, H.E., Qiu, L., Tan, J., Gloss, B., Augustine, G.J., Deisseroth, K., Luo, M., Graybiel, A.M*., et al.* (2011). Cell type-specific channelrhodopsin-2 transgenic mice for optogenetic dissection of neural circuitry function. Nature methods *8*, 745-752.

Data format

Meta Data File (".mat")

See general description from the lab.

Processed Object File (".mat")

Each .mat data file contains data from one session. The data is in the format of matlab structure. Each structure contains the following fields:

Top level data description

timeUnitIds: A vector of integers, with the following convention: 1--ms; 2--second; 3--minute; 4--hour; 5—day.
timeUnitNames: Description of time units in **timeUnitIds** (e.g. "second").

descrHash: contains the directory and filename of the raw data file.
descrHash. keyNames: type of data (e.g. "original behavioral data").
descrHash. descr: more detailed description of the entries in **descrHash. keyNames.**
descrHash. value: directory and filename of the entries in **descrHash. keyNames.**

Behavior data

trialTimeUnit: specifies the time unit of the data (refers to **timeUnitIds** above).
trialTypeStr: description of the rows in **trialTypeMat** (e.g. ""HitR", "HitL", "Photostim").
trialTypeMat: each column describes one trial by the description in **trialTypeMat** (e.g. a "lick left" trial in which the animal correctly reported choice will have a entry of "1" for "Correct lick left" and "0" for "Error lick left". A phostostimulation trial will have "1" for "StimTrial"). The photostimulation waveform is stored in "**timeSeriesArrayHash.value{(1)}.valueMatrix**" (see below).
trialIds: trial number to reference to the trials.
trialStartTimes: start times of the trials. The time is referenced to session start, (i.e. time 0 is the start of the session).
trialPropertiesHash: contains detailed information about trial structures and timing information. It has the following sub fields:
trialPropertiesHash.**keyNames**: {'PoleInTime' 'PoleOutTime' 'CueTime' 'GoodTrials' 'PhotostimulationType'}.

PoleInTime is the start of sample period for each trial, in units of seconds, relative to **trialStartTimes**.

PoleOutTime is the end of the sample period and start of the delay period. CueTime is the end of the delay period. Time is in units of seconds, relative to the start of the trials.

GoodTrials has values of "0" or "1"; trials with "0" entries should be discarded for analysis, these indicates periods in the session when mice are not performing (e.g. during periods of passive photostimulation). For non-performing trials, the 'PoleInTime', 'PoleOutTime', 'CueTime' 'PhotostimulationType' all have entries of "NaN".

PhotostimulationType has the following values:
"0"--non-stimulation trials; ...
"1"-- Fastigial photoactivation (contralateral to ALM recording); sample; 500ms (5ms pulse, 20Hz);...
"2"-- Fastigial photoactivation (contralateral to ALM recording); delay; 500ms (5ms pulse, 20Hz);...

"3"-- Dentate photoactivation (contralateral to ALM recording); sample; 500ms (5ms pulse, 20Hz);...
"4"-- Dentate photoactivation (contralateral to ALM recording); delay; 500ms (5ms pulse, 20Hz);...

"5"-- DCN photoinhibition (contralateral to ALM recording); delay; 500ms (40Hz cosine);...
"6"-- DCN photoinhibition (contralateral to ALM recording); delay; 1.3s (40Hz cosine);...

"7"-- left ALM photoinhibition (ipsi to DCN recording); delay; 1.3s (40Hz cosine);...
"8"-- right ALM photoinhibition (contralateral to DCN recording); delay; 1.3s (40Hz cosine);...
"9"-- bilateral ALM photoinhibition (DCN recording); delay; 1.3s (40Hz cosine);...
"10"-- bilateral M1 photoinhibition (DCN recording); delay; 1.3s (40Hz cosine);...

'"NaN and others"--discard (stimulation configuration for other purposes, should not analyze)';...

trialPropertiesHash.**descr**: describes entries in **keyNames.**
trialPropertiesHash.**value**: contains the values of the properties in **keyNames** for each trial. The time is referenced to trial start, (i.e. time 0 is the start of the trial).

timeSeriesArrayHash: contains the time series data for behavioral monitoring and photostimulation. It has the following sub fields:
timeSeriesArrayHash. keyNames: {"EphysVars"}, these data are collected in Ephus acquisition software (ephus.org).
timeSeriesArrayHash.**descr**: describes the content of the data: the data contains recordings of tongue movements (see methods) and photostimulation waveforms.
timeSeriesArrayHash.**value**: contains the data for each trial
obj.timeSeriesArrayHash.value{(1)} contains:
id: e.g. [1 2], channel numbers in Ephus acquisition software, the number of channels should match the number of columns in **valueMatrix.**
idStr: e.g. {'aom_input_trace' 'laser_power'}, description of the time series data from corresponding channels in **id**.
Channel 1 is typically photostimulation waveform.
Channel 2 is laser power delivered into tissue in units of mW
idStrDetailed: more detailed description of idStr.
timeUnit: time unit used in **timeUnitIds**.
time: e.g. [16150000x1 double], time stamps for the time series data, this is in session time, time 0 is session start. To align to trial start, use **trialStartTimes,** or subfield **trial.**
trial: e.g. [16150000x1 double], trial number for each sample in the time series, the trial numbers are according to **trialIds** (see above).
valueMatrix: e.g. [16150000x3 double], time series data. The number of columns should match number of channels in **id**. The number of samples should match time stamps in **time.**

Ephy data

eventSeriesHash: contains the spike times as well as neuron information; each entry is data from one single unit or multi-unit site
eventSeriesHash.keyNames: name of the entry (e.g. "unit1", or "site1").
eventSeriesHash.descr: description of the entry (e.g. "single unit 1").
eventSeriesHash.value: each entry contains the data structure from one neuron.
Each structure has the following fields:
timeUnit: time unit of the data (refers to **timeUnitIds** above).
eventTimes: spike times for all the events. The time is referenced to session start, (i.e. time 0 is the start of the session). To obtain trial aligned spike time, reference to the trial start time in **trialStartTimes.**
eventTrial: this vector indicates which behavior trial in **trialIds** the spike times were from.
waveform: snippets of spike waveform. Each snippets are 30 samples long.
depth: estimated depth of the neurons, in micrometers.
channel: which channel on the silicon probe the neuron is recorded from. (see "meta data" file for silicon probe site locations and configuration).
cellType: {"pyramidal" or "FS"**}.** "Pyramidal", putative pyramidal neuron identified by waveform shape; "FS", putative fast spiking neuron identified by waveform shape. If a cell has no entries, it is unclassified.

Raw voltage trace data (many ".mat" files)

Files are stored in directory ".\RawVoltageTraces\". Each .mat data file contains data from one session. These files are referenced according to trialID in the processed object file (in "**descrHash.values**").

Each voltage trace data file contain the following variables:

Bitcode_allCh – for housekeeping and synchronization.
Trigger_allCh – for housekeeping and synchronization.
allOther_allCh – for housekeeping and synchronization.
ch_MUA – *n* x 32 matrix, containing 32 channel recording data.
TimeStamps – n x 1 vector, containing time stamps for voltage recording data. Time is referenced to trial start (t=0). (refer to "**trialStartTimes**" in the processed object file).

Only "ch_MUA" and "TimeStamps" are useful. Others are for housekeeping purposes.

How to get started

We have included the following demo files to get started with this dataset.

Demo_get_performance(example_session_data_object) – extract and plot the behavioral performance data in %correct

Demo_get_trial_aligned_raster_PSTH(example_session_data_object) – extract and plot the spike times information and plot the trial aligned PSTH and raster